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# AN ECONOMIC-ENGINEERING OPTIMIZATION FOR THE BINATIONAL MEXICO-US LOWER COLORADO RIVER DELTA: THE MEXICALI VALLEY CASE STUDY

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# An Economic-Engineering Optimization for the Binational Mexico-US Lower Colorado River Delta: The Mexicali Valley Case Study

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**Abstract**

Agricultural water use in the bi-national Lower Colorado River Basin is about ninety percent of all the beneficial use. Fast growing border cities in Baja California and agricultural water conservation may increase urban water allocations in the near future. The CALVIN economic-engineering model was used to evaluate the benefits and costs of a variety of water management strategies in the Lower Colorado River Delta in Mexico. Results show that for 2020 water demand conditions, agriculture seems to be the most suitable donor of water to other sectors. Wastewater reuse for irrigation and water conservation may reduce dependence on agricultural water reallocation to fulfill future demands.

## Introduction

Population growth and increasing environmental awareness are rapidly expanding pressures on water managers and agricultural water use in many developed and developing regions. Long-term water resource planning requires systems analysis tools, that can integrate water management options with physical infrastructure, economic costs and management institutions. A quantitative understanding of a problem is imperative in this planning process. Insights from a comprehensive quantitative analysis are useful to elicit promising water resource management alternatives when future supply is at a stake.

This paper offers some insights from a case study of one of Mexico's driest regions, the Colorado River Delta (CRD). This study is motivated in part by increasing concern among the scientific community, NGOs and governments in Mexico and the United States on the threat to ecosystems in the CRD due to low flow regimes in the Colorado River through the Gulf of California (e.g. Pitt 2001; Anderson *et al.* 2003). The economic value of water for both agricultural and urban uses at year 2020 levels is estimated. Taking into account operating costs, as well as institutional and infrastructure constraints on water allocation; this study seeks to estimate the economic value of designated minimum flows for conservation purposes in the CRD. Preliminary findings in this study under optimized operations indicate that agriculture in the Mexicali Valley is the likely donor of water to meet conservation and urban needs. Although the Mexicali Valley is one of the regions in Mexico with more active water markets (Kloezen, 1998; Hearne and Trava 1997), further institutional and infrastructure changes are needed to lower transaction costs and risks of water trades among users.

**Case Study: The Lower Colorado River Delta in Mexico**

The Mexican portion of the Lower Colorado River Delta (CRD) currently occupies more than 180,000 hectares, which is estimated to be only 10% of the Delta's area in the early 1900s (Glenn *et al.* 2001). The Colorado River is the main source of water for northern Baja California, whose rainfall averages roughly 200 mm/year. The CRD is the breeding ground for thousands of migratory birds as part of the Pacific Flyway and home of endangered species including the Yuma clapper rail and the desert pup fish (Anderson *et al.* 2003). Since the 1930s, upstream diversion for agricultural and urban uses have greatly reduced and altered the pattern of Delta flows, causing severe habitat loss, deterioration of water quality, and abetted invasions of exotic species (Glenn *et al.* 2001). Migratory birds have suffered reduced wetland and wintering habitat (Zengel *et al.*, 1995). Endangered species such as the Yuma clapper rail rely on cattail habitat for breeding. The bird populations are prone to collapse because low flow regimes affect cattail coverage (Hinojosa Huerta *et al.* 2002). Most of the remaining CRD is a protected area part of Biosphere Reserve of the Gulf of California since 1993. Nevertheless, severe droughts, stagnant or increasing agricultural and urban demands, and institutional constraints make restoration of the CRD a real challenge.

In 1944 Mexico and the USA signed a Water Treaty which guaranteed 1,850 million cubic meters of water per year (about 10% of the Colorado River's unimpaired flow) to Mexico through the Colorado River. Other issues were to be addressed through the newly created International Boundary and Water Commission (IBWC). Unfortunately, this water treaty did not address population growth or water quality. In the early 1960's as a result of drainage water from the Central Arizona Project, salinity went beyond the historical 1000 ppm level (Garcia-Acevedo 2001). This caused tremendous harm to the bilateral relationship Mexico-USA. After long rounds of negotiation it was not until 1973 when Minute 242 was signed by both countries. The US section of the IBWC agreed to deliver water to Mexico with a salinity level less than 130 ppm (±30 ppm) above the salinity observed at the US Imperial Dam.

Minute 306 to amend the 1944 water treaty required that both countries coordinate efforts for restoring the CRD including the identification of additional sources of water. More recently, in 2004 the reformed Mexican National Water Law put environmental uses prior to hydropower and industrial uses in the order of allocation.

Salinity and flow regimes determine the vegetation coverage in the CRD (Zengel *et al.*, 1995; Glenn *et al.*, 1998). *Clinton et al.*(2001) and other studies argue the main cause of the problem is low flow regimes. Salt concentration is increased as a result of disrupted water flows due to upstream diversions (Coehn *et al.* 2001). Vandersande *et al.* (2001) argue salt tolerant plant species out-compete native plant species under low flow regimes. Once invasive species are established, native vegetation can hardly recover. Stromberg (2001) discuss the causal relationship between flow regimes and ecosystem functions in the CRD. The riparian corridor of the CRD requires annual flows of about 40 MCM, with pulse flows of 320 MCM every four years (Luecke *et al.*1999; Pitt *et al.* 2000). Studies in the region seem to agree on the amount of water needed for restoration and maintenance of the CRD habitat. However, the costs and regional management of dedicated flows are largely unexplored.

However, even when water exceeding the 1,850 MCM quota reaches the Mexican border, this water has been assigned to agricultural uses and sometimes to aquifer recharge (*Clinton et al.* 1999). Other causes of the low-flow regime problem point to the increasing population in the fast growing cities in the border of Baja California. Table 1 details water sources and uses in the CRD.

**Table 1: Water Supplies and Allocations in Irrigation District 014***

| Source/Use | Quantity (TAFY) |
|---|---|
| *Supplies* | |
| Treaty | 1,500 |
| Groundwater | 730 |
| Conveyance Losses | (645) |
| **Net Available Supply** | **1,585** |
| *Allocations* | |
| Irrigation | 1,425 |
| Mexicali Municipal and Indust. (M&I) | 66 |
| Tecate M&I | 3 |
| Tijuana M&I | 65 |
| Ensenada M&I | 7 |
| San Luis Rio Colorado M&I | 19 |
| **Total Allocations** | **1,585** |

**Adapted from Clinton et al (2001)*

## Method

This study uses deterministic network flow optimization within the framework of a computer model called CALVIN (Jenkins *et al.* 2001, 2004). The CALVIN model is a systems analysis tool developed and successfully applied for strategic water management in California. The model optimizes and integrates water operations and allocation based on costs and economic water scarcity for urban and agricultural users (Medellin and Lund *in press*). The CALVIN model has provided promising insights for water management regarding water markets, facility expansion, dam removal, conjunctive use, economic costs of environmental restrictions, and users' economic willingness to pay for water (Lund *et al.* 2003; Jenkins et al, 2004; and Null and Lund 2006). Most recent applications of CALVIN include adaptations to climate change for the state of California. (Tanaka *et al.* in press; Medellin *et al.* 2006).

Coverage of CALVIN in Baja California is depicted in Figure 1. Urban demands include the cities of Ensenada, Mexicali, Rosarito, San Luis Rio Colorado (Sonora), Tecate and Tijuana. Agricultural water uses include the valleys of Guadalupe, Maneadero and Mexicali. Hydraulic infrastructure in the model includes major canals and aqueducts, pumping stations, reservoirs and aquifers. For the Mexicali Valley, which is the focus of this paper, hydrological data includes time series of inflows from the Colorado River through the Mexico-U.S. border, and estimates of aquifer recharge for the Mesa Arenosa de San Luis Rio Colorado and the Mexicali aquifers. Data availability permitting, a time span of 30 years (1970-2000) is the base historic hydrology for this study.

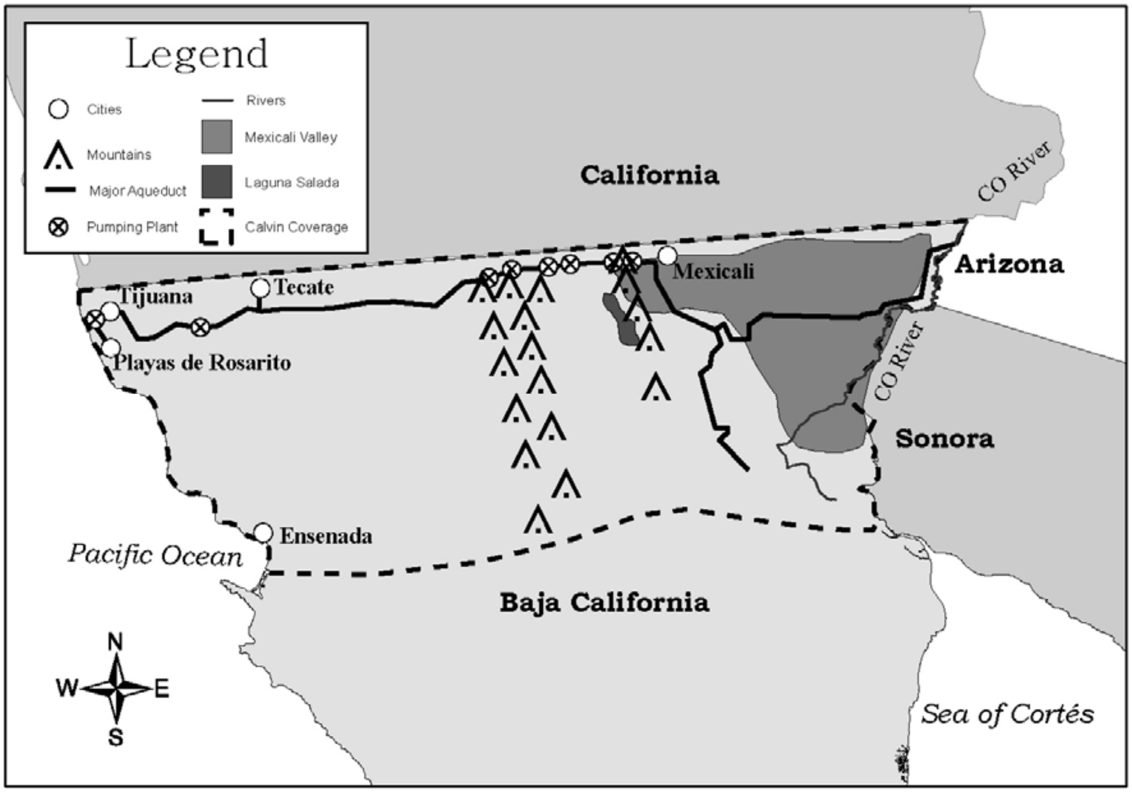


**Figure 1 CALVIN-Baja California Coverage (after Malinowski 2004).**

A key component in the development of a CALVIN model is estimation of the economic values of water for each agricultural and urban water use location. Optimization in CALVIN involves both operating costs and economic value of scarcity. Water scarcity costs are represented by convex penalty functions developed from piece-wise linear integration of a marginal willingness-to-pay curve for water for each user.

In the case of agriculture, an inductive valuation technique known as positive mathematical programming (or PMP after Howitt, 1995) is used to estimate shadow values of water for a particular region. In this sub-model called SWAP (Howitt *et al.* 2003), a positive representative producer maximizes profits assuming water and land are the limiting factors. Production specification is given by a constant elasticity of substitution production function, which restricts substitutability among factors such as land, water, labor and supplies. SWAP calibrates exactly at observed values of factor usage and total output. Willingness to pay for water is obtained by increasingly restricting water availability to farmer.

Data for SWAP in the Mexicali Valley is a balanced panel from CNA's irrigation district records on 60 months of water deliveries and cultivated land per crop and irrigation sub-district (*módulo*). Production costs and factors usage (besides land and water) were obtained using statistical information from the Agriculture Ministry (SAGARPA). Finally, the 23 *módulos* where consolidated into four major groups considering geographical location, water sources and other characteristics. These four groups are 1) Main Mexicali Valley, 2) Mostly groundwater, 3) East-side (San Luis Rio Colorado), and 4) South of the valley agriculture. Shadow value of agricultural water can be as high as $40 dollars per thousand cubic meters, at observed water use levels. This value is almost six times the water fee paid to the *modulos'* administration for the water service.

Estimation of an urban water demand curve for Mexicali follows the procedure detailed in Jenkins *et al.* (2003). Urban demand has four components: residential (76%), commercial (9%), industrial (9%) and government (10%) according to the Mexicali water utility's (CESPM) statistics. Residential and all other uses were the two consumption blocks considered. A constant price-elasticity of demand of -0.2 for residential demand and -0.3 for industrial demand were assumed. Residential projections for year 2020 demands account for population projections from INEGI and CONAPO (respectively, the Mexican statistics and population council institutes), at current per capita consumption levels from CESPM. Other consumption is assumed to grow at the same pace as residential demand. Conveyance efficiency is assumed to remain at its current 86% level. Since water for all uses is priced using an increasing block rate structure, a weighted average price of $0.32/m$^3$ was used to estimate the economic value of water. Projected total urban Mexicali water demand for year 2020 is estimated to be 110 MCM/year.

**Results**

The economic value of water is obtained by numeric integration of marginal willingness to pay curves on agricultural and urban uses. Penalty functions have a value of zero whenever the target demand is fulfilled, and total cost increases at an increasing rate when shortages occur. Figure 2 shows an example of these economic penalties for one irrigation area and urban uses for a winter and a summer month. Urban scarcity costs are substantially higher than those for agricultural uses. Thus, with economically optimized allocations shortages typically affect agriculture first. Seasonality also is apparent in Figure 2 as summer months have both higher demand and scarcity values.

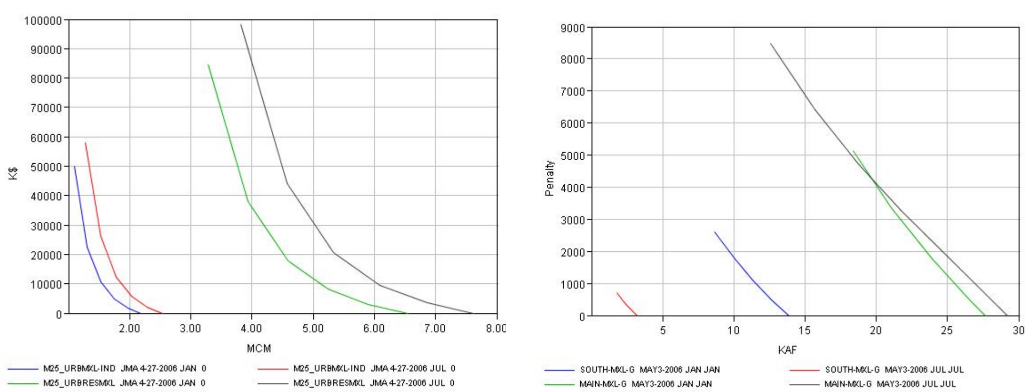


**Figure 2 Urban and Agricultural Penalty Functions in Mexicali.**

Preliminary model runs using the CALVIN network for Mexicali show that indeed shortages occur for agriculture in some months even if no additional water is dedicated for environmental purposes in the CRD. Water scarcities can be as high as 20 MCM /year. When population growth in the cities of Tijuana, Tecate and Rosarito is considered, and minimum recommended environmental flows are mandated for the ecosystems in the CRD, water scarcity and scarcity costs increase substantially. If population increases by roughly 40% (according to CONAPO) and Rio Colorado-Tijuana aqueduct is expanded by 30%, an increase in the water scarcity for agriculture of about 183% (roughly 51 MCM) is expected. This scenario assumes Mexico will still receive the 1944 treaty allocation and no substantial improvements in water use efficiency in agriculture occur. Also, it assumes a monthly average of the recommended minimum environmental flow (about 7.5MCM) is expected to reach the Gulf of California.

## Conclusions

Systems analysis using CALVIN makes it possible to improve understanding of problems involving water resources management. Results from this exercise confirm that if economic efficiency is pursued, sectors with the lowest economic value of water resources are affected the first. Further development of the CALVIN model in Baja California may help elicit smart water management strategies for achieving future water demands and conservation goals.

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http://cee.engr.ucdavis.edu/faculty/lund/CALVIN/